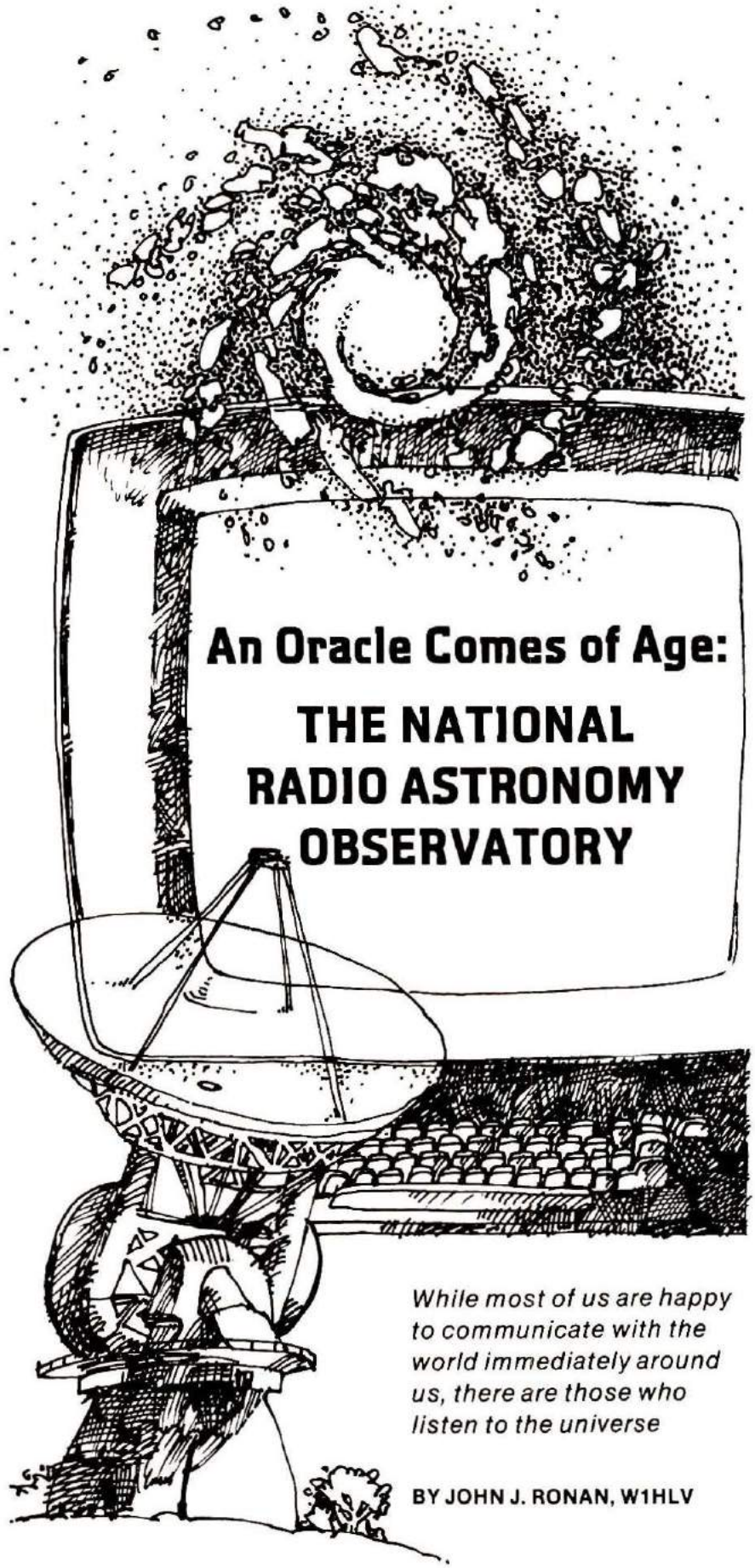


An Oracle Comes of Age:

THE NATIONAL RADIO ASTRONOMY OBSERVATORY

While most of us are happy to communicate with the world immediately around us, there are those who listen to the universe

BY JOHN J. RONAN, W1HLV

Skyline Drive — one of the most scenic roads in the eastern part of the country. A pathway to numerous camping sites, hiking trails, picnic areas — an escape-to-tranquillity for many of the inhabitants of the busy seaboard areas of North Carolina, Virginia, and the District of Columbia. The Drive is an aptly-named part of the Blue Ridge Parkway which follows the ridges and turns of the mountain range that is encompassed by the Shenandoah National Park. From a scenic overlook near the southern end of the Drive you can look east toward Charlottesville on the busy highway from Richmond, Newport News, Washington, and Colonial Williamsburg.

The view to the west is inspiring; mountain ranges pile up one behind the other, with always a distant blue tip hinting of more to be found beyond the last range in sight. Somewhere to the southwest, near the second and third ranges to be seen, is another town that is the western terminus of a trek by many a scientist, engineer, and technician. Green Bank, West Virginia — the name is suggestive of pastoral calm and is not inappropriate. From the quiet, self-confident bustle of Charlottesville to the peace of Green Bank there is little to denote that they are both vital parts of an effort to listen to a universe that man has never heard. The discipline that ties the two together is Radio Astronomy; a field that requires both the serenity of an area isolated from the electronic hubbub of the business world and an administrative center with access to that same world with its computers and technology.

The science of radio astronomy is less that 100 years old. Yet, there are over eighty major installations in the world today, their dishes dotting each of the continents like miniature lunar craters.

Some of the sites — Jodrell Bank in England, Arecibo in Puerto Rico, Vermillion River in Illinois, Hat Creek in California — are well known and beginning to acquire the romance always associated with stars and distant galaxies.

But the vortex of radio research is in Charlottesville, Virginia, hard by the Blue Ridge Mountains, at the National Radio Astronomy Observatory (NRAO). Now 23 years old, the obervatory was born in 1954 out of talks between Carnegie Institute, Cal Tech, and the National Science Foundation (NSF). Like its sister institution, Brookhaven National Laboratory, NRAO is operated by the Associated Universities, Incorporated (AUI), a non-profit organization made up of Columbia, Cornell, Harvard, Johns Hopkins, Massachusetts Institute of Technology, Pennsylvania, Princeton, Rochester, and Yale.

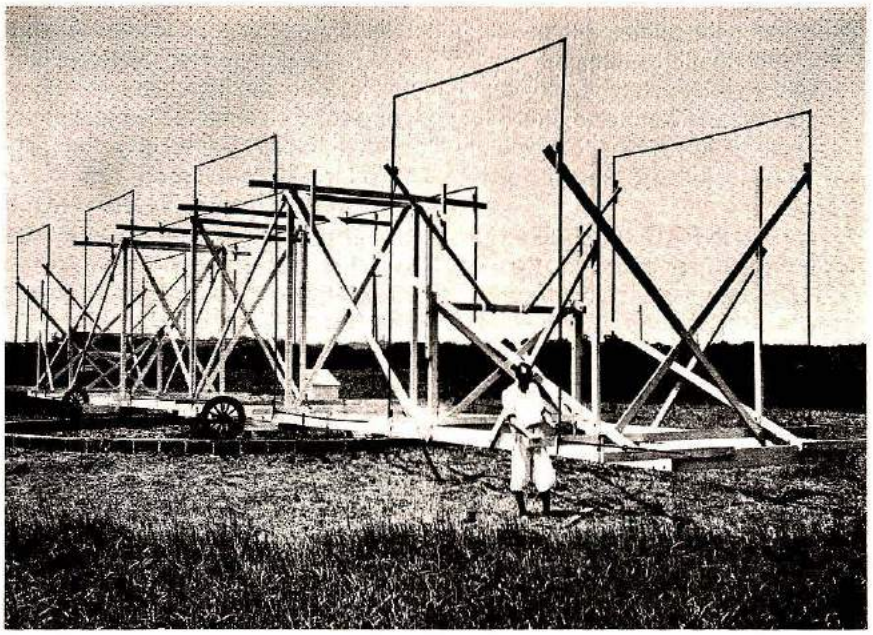
Created in 1946, AUI's mission was to run large-scale research facilities which are beyond the economic clout of any single school. NRAO, one of the largest radio-astronomy complexes in the world, with an annual budget nearing $20,000,000, certainly fits that description.

AUI, whose president is Gerald Tape, is steered by a Board of Trustees. Both of the facilities under AUI's guidance get most of their financial support from the federal government: Brookhaven from the Atomic Energy Commission, and NRAO from the National Science Foundation, which are both major sources in this country of "clean," or non-defense, money; a fact that both Brookhaven and NRAO scientists are proud to point out.

NRAO itself is run by a director, now David Heeschen, who manages the budget and over 200 NRAO employees. The elite core of that staff, averaging only 30 members, is made up of the astronomers themselves — the scientific research staff.

The secret behind that small number is another facet of NRAO's existence: It is primarily a visitor institution. Though its staff generates a good deal of the experiments, half of the observatory's purpose is simply to provide access to its equipment for anyone with an approved program, whether American or foreign. And it does serve that purpose: Over 60 per cent of the time on the telescopes is spent by non-NRAO personnel.

Programs run through NRAO have accounted for some spectacular discoveries, such as the first detection of a pulsar* by American astronomers, and later the



One of the pioneers in Radio Astronomy, Karl Jansky, used this antenna array at the Bell Telephone Laboratories to discover radiation from the Milky Way. His work in 1930-32 was intended to study the interference that bothered transatlantic radio telephone circuits. A replica of this antenna stands at Green Bank, West Virginia (*Bell Laboratories photograph courtesy of NRAO*).

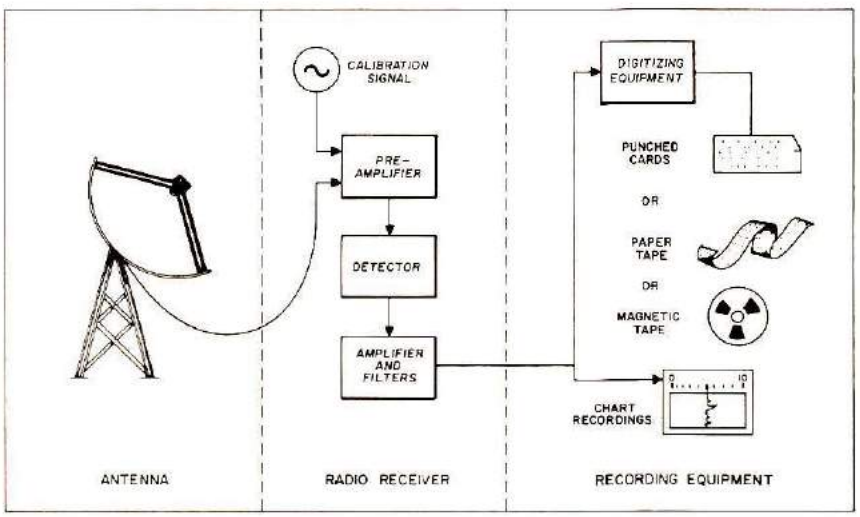


Fig. 1. Here is a simplified block diagram of the sophisticated technique that turns the static-like noise from a distant star or galaxy into something that astronomers can interpret.

***Pulsar**: A rapidly rotating star approximately of the mass of the sun, but of much higher density. They emit regular pulses of radio radiation, once or twice per rotation. The Crab Nebula pulsar has also been observed optically and in x-rays.

detection of a pulsar in the Crab Nebula. This second discovery, in November, 1968, was important because the Crab pulsar is one of the few that is both a radio and a light source.

It was at NRAO that the first measurement of a magnetic field in hydrogen clouds was made, and it is at NRAO that the continuing study of the structure of the galaxies goes on. On a "local" level, the NRAO staff has examined the radio emissions of the planets, especially Venus and Mars. The information, on both atmosphere and ground characteristics, has been used by NASA to help solve practical engineering problems.

Shopping for time

Exactly who gets time for what experiments is determined by an elaborate screening process. It begins when NRAO or visiting astronomers submit a proposal, usually months in advance, that not only states the purpose of the experiment but also requests a certain telescope and receiver. Generally, larger telescopes (antennas) are efficient at longer wavelengths, but the precise wavelength used is determined by the receiver, just as in household radios.

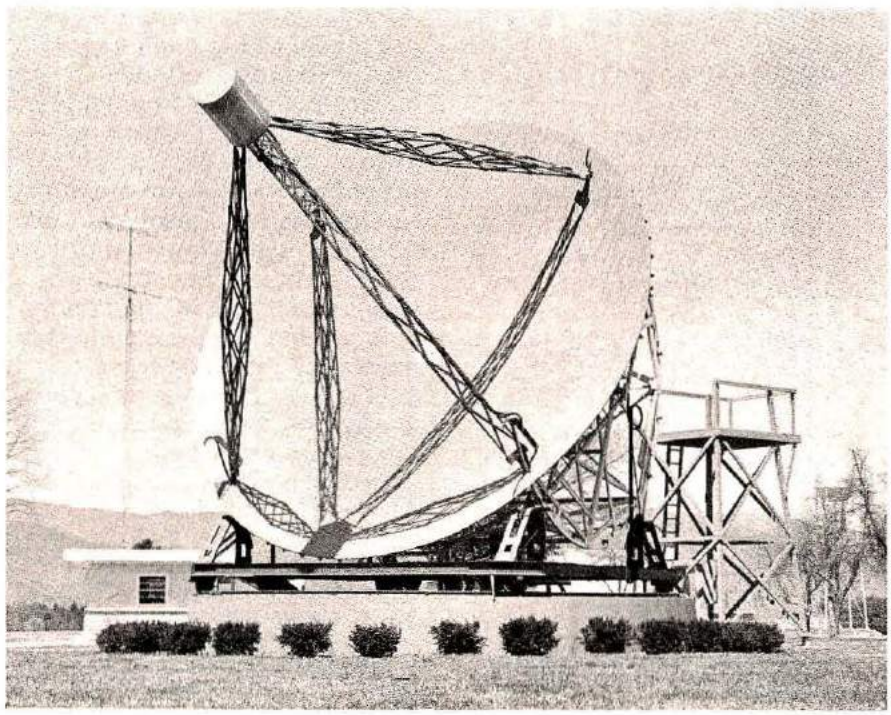
Though the actual process is far more complex, the telescopes and receivers are interchangeable in somewhat the way tuners and speakers are in large stereo shops.

The astronomer — or shopper — can request any combination, depending on the "sounds" he is after. The astronomer goes further; he specifies the exact location in the sky as well as the duration of tracking time. Then, he waits.

The NRAO administration hands the proposal over to three independent, anonymous, referees who judge the individual proposals solely on merit. Since NRAO is a visitor institution, its staff is in direct competition with radio astronomers from other observatories. They bid against one another for the telescope's time. The decision of the judges, as in other contests, is final.

A closer look at one of the 85-foot antennas. This is the Howard E. Tatel telescope, one of the oldest at the observatory. It is the fixed part of the interferometer array; the other two are movable along a track in order to obtain a variable baseline (*photo courtesy NRAO*).

Another early explorer of the radio universe was Grote Reber. He built his antenna in 1937, using 26-gauge galvanized iron sheet for the surface. It cost approximately $4000 at that time, and weighed approximately two tons exclusive of the turntable. Grote explored the 160- and 480-MHz area from his backyard in Wheaton, Illinois. While not exactly a mobile piece of equipment, nevertheless it was moved from Wheaton to Sterling, Virginia, then to Boulder, Colorado, and finally to NRAO at Green Bank. It was restored under Reber's supervision in 1959-60, and stands at the entrance to the West Virginia site of NRAO (*photo courtesy NRAO*).

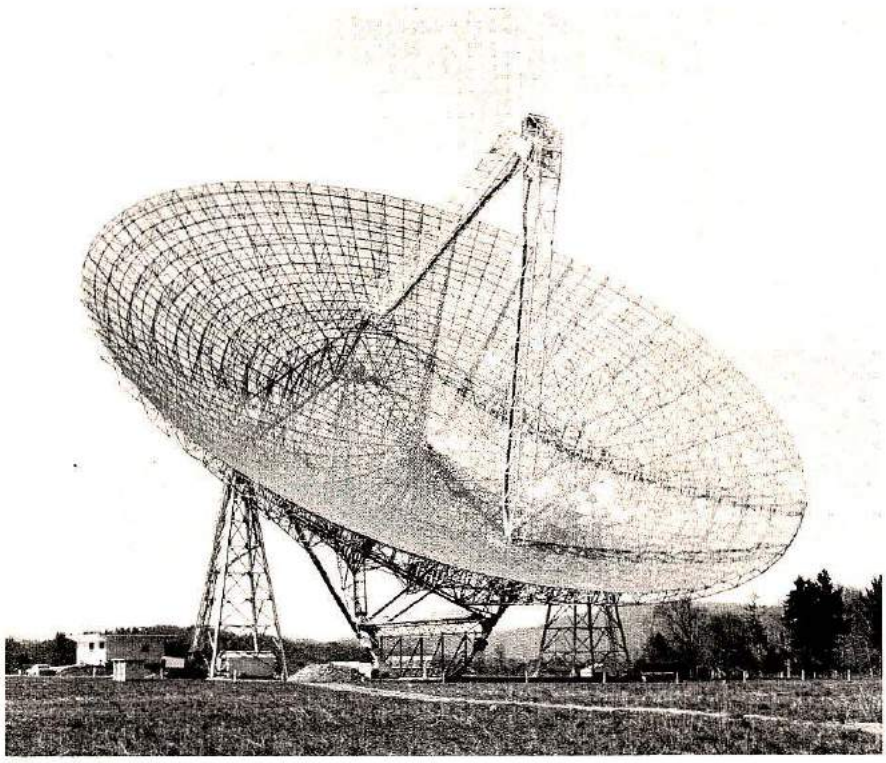


If a proposal is approved, it is given to the Chief Telescope Operator who in turn gives it to the Duty Operator assigned to the appropriate instrument. The astronomers are never actually allowed to operate the telescopes.

Finally, the experiment is run while its sponsor, somewhat of a tourist for the time being, waits. Once the data is recorded and analyzed, boxes of read-out sheets are at last offered up, like the riddled responses of the ancient oracles, to the man who asked the questions.

Research facility

The purity of scientific research in Charlottesville is complemented by the



A diameter of 300 feet (91 meters) makes this radio telescope at Green Bank an awe-inspiring sight. The first American to discover a Pulsar used this dish to do so in 1968. Some idea of the size can be gotten by comparison to a football field or by considering that many houses in urban areas are on land areas less than one-quarter of the antenna size (*photo courtesy NRAO*).

atmosphere. The single, three-story brick building that is NRAO headquarters sits quietly at the base of one of the Blue Ridge's foothills, near Thomas Jefferson's University of Virginia. In fact, the structure is leased from the university and the legal tie, along with the physical proximity, gives NRAO much of the colonial calm that Jefferson designed into the University of Virginia.

Visitors come to the glassed-door entrance by way of a circular drive that loops around a large bed of ivy and through the invisible scent of dogwood. Once inside, the mood and pace seem almost monastic. The full-time members of the scientific staff, which has been all male for most of NRAO's history, work in cell-like offices, poring over data that has been disgorged by the IBM 360/65 which is housed in the basement.

Occasionally, a hand flutters over a desk calculator or someone pads down a long, Holiday-Inn-like corridor to consult with a colleague. Such conversations, heard from a distance, are a garble of syllables marked only by the general lilt and dip of the language; the topic could be baseball. But when the words come clear they are not likely to be about home runs: "... so it looked like the galaxy dropped by a hundred in flux on the same scan ... no indication of change in the spectral index ... $10^3 D_r^2\ cm^2$ ..." Whatever, it is not baseball.

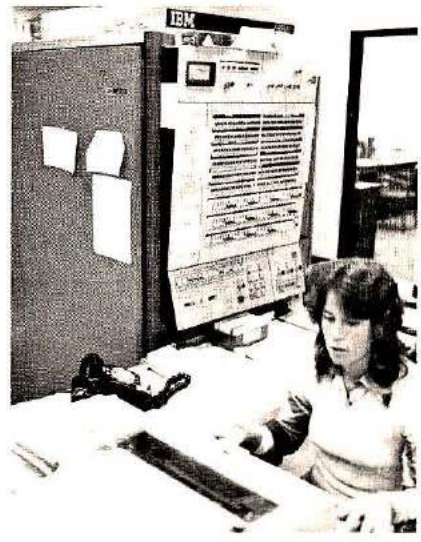
Reflecting NRAO's university origins, the research staff retains the academic ranking system that includes, at the top, tenure. Moving from the most temporary to the tenured, the ranks are Research Associate, Assistant Scientist, Associate Scientist, and Scientist. The academic penchant for word play, where years of work and study mean the moving of "Associate" from the right to the left, is obvious.

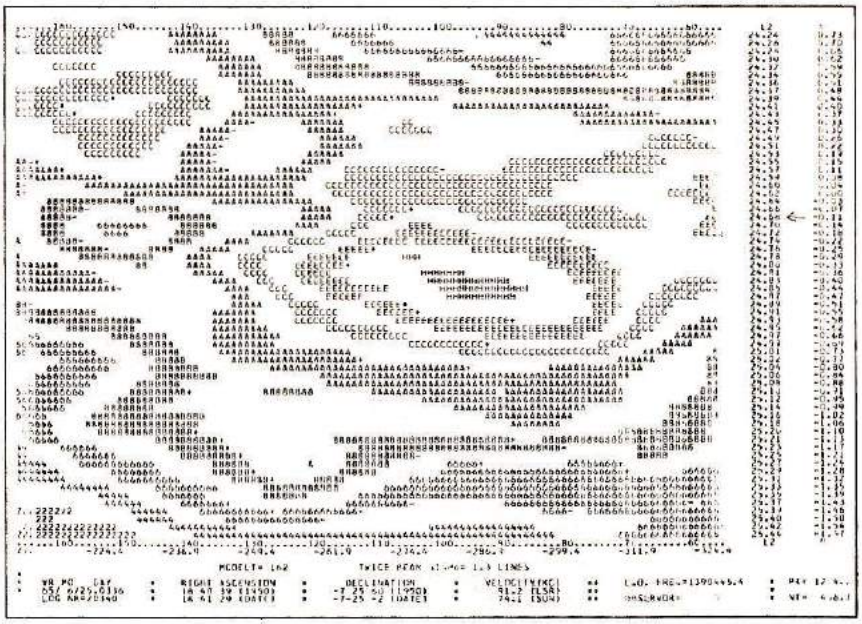
But through the word-murk, the ladder is clear. Most of the Scientists are tenured and those below are on short-term appointments, ranging from one to three years. The largest single group of staff members, the Research Associates, are on one- to two-year appointments. Unfortunately, this points to one of NRAO's few flaws — insistence that the rapidly changing staff produce quick, visible results, a parallel to the old academic "publish or perish" demon.

Still, the observatory thrives. One of the most striking projects at NRAO is the search for organic matter in inter-stellar and inter-galactic space. The existence of organic molecules outside of a life environment was once thought impossible but, now, almost thirty different molecules are known to exist in free space. About two-thirds of them were discovered through NRAO.

It is amazing that this research has shown the existence of such complex structures as acetaldehyde (CH_3CHO), used on earth in the manufacture of perfume, methyl alcohol (CH_3OH), commonly known as wood alcohol, and formic acid (CHOOH), the substance which makes a bee sting painful.

The computer used in data reduction is an IBM 360/65. Here Sharon Spooner at the Charlottesville center puts the machine through its paces cranking out the numbers (*photo courtesy NRAO*).





Computers are used to reduce the received signals to a contour map that is more readily interpreted. This is the intensity chart of the 21-cm hydrogen line as taken through the constellation of Scutum (*NRAO photo*).

Further, it gives new, positive, clues to the problem-of-problems in all space research — the quest for life.

These are staggering feats for a science just 87 years young. It was only in 1890 that Thomas Edison, pausing between phonograph and vitascope, proposed construction of a radio telescope near Sussex, New Jersey. Edison wanted to encircle a field with telephone wire and "listen" to the sun. The experiment even got so far as the delivery of the poles, but they were never erected. More interested in profitable patents then in radio astronomy, Edison let the experiment languish.

No matter; the instrument would have been too insensitive to work. By contrast, NRAO's telescopes are able to detect signals many light-years distant. It has been estimated that the radio energy that they, and all other radio telescopes, have collected over the past twenty years, is equivalent to the energy expended by the fall of a single snowflake!

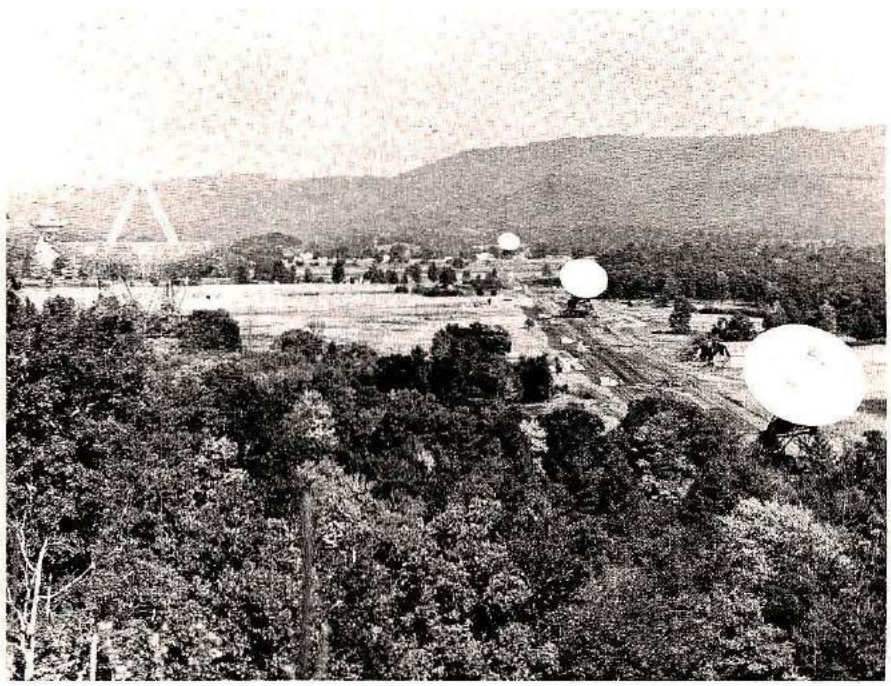
To get a look at these delicate beasts a visitor must leave Charlottesville. NRAO's dishes are located 120 miles west, in Green Bank, West Virginia, nestled between the Allegheny and Back Allegheny ranges of the Appalachians.

The trip from Charlottesville, except for the destination, is a trip into the past. It takes three hours on State Highway 250 as the two-lane road twists and toils its way over range after range of mountains, beginning with the Blue Ridge. Beyond West Augusta, in extreme western Virginia, 250 cuts through the George Washington National Forest and seems, at times, to pass by permission of the trees alone.

Past Headwaters, 250 enters some of the remotest country east of the Mississippi. The villages here — McDowell, Monterey, Hightown, through which 250 inevitably becomes the Main Street — are the type where four-bladed ceiling fans survive and turn so slowly in summer, that flies ride them to cool off. They are the last bastions of the eight-ounce Coke. They are America forty years ago.

Then, turning south onto West Virginia Highway 28 to enter Deer Creek Valley, the driver nears Green Bank, elevation 2700 feet, with 1300 additional feet of green

Not the valley of the dolls, but the valley of the dishes. The row of 85-foot radio telescopes at the right are in an interferometer array that is 5000 feet (1.52km) long. The 300-foot antenna, left, and the 140-foot equatorially-mounted unit, far left, are both in their "stow" positions for maximum safety in windy weather (*photo courtesy NRAO*).



mountain protecting it to the east and west. Here, in the "Wilderness State," three miles north of town, there suddenly appears, like the first view of the invading machines in *War of the Worlds*,* a field of telescopes. They are gawky, awkward things, each topped by a huge metal dish. Like lunar landers, satellites, and other apparatus built for work in space, they are without even the pretense of a single streamed line. They obviously have to do with worlds far removed from West Virginia.

Spread over a 2700 acre tract, there are eight telescopes. Wally Oref, the Public Information Officer for NRAO, runs an extensive tour and information service during the summer, and visitors are also free to walk the grounds by themselves. But only walk: sparking automobiles wreak havoc with the receivers.

A stroll around all the telescopes is long, about three miles, and over largely untouched terrain, since the Green Bank operation is as ecologically "clean" as the money that built it. Deer Creek is unpolluted and cattle are allowed to graze up to the very shadows of the telescopes. In fact, it's not unusual to be gaping at a mammoth dish, perhaps tuned to the other end of the universe, and discover that you have put your foot in a more earthly texture, courtesy of the cows.

Among the telescopes at Green Bank are three 85-foot instruments that, together, form an interferometer. One of the elements is fixed and two moveable so that, working together, they are able to simulate a telescope equal in diameter to the separation of

War of The Worlds, a book by H.G. Wells, was used as an early Science-Fiction radio broadcast by Orson Welles. It portrayed an attempted invasion of this planet by creatures from Mars. Because the fictional landing site for the alien ships was in New Jersey, the 1939 broadcast caused wide-spread panic among residents in that part of the country.

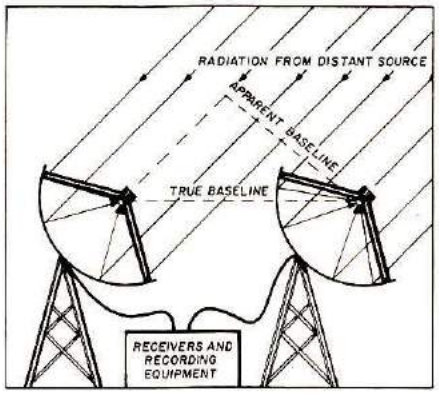


Fig. 2. An interferometer is an instrument that can map the position and characteristics of distant signal sources by making use of the pattern peculiarities of two or more antennas linked together electronically. Because of phase differences in the wave arriving at separate locations, one part of the pattern will be reinforced, another part will be cancelled. A computer can use this information to determine relative size and somewhat precise location of the source.

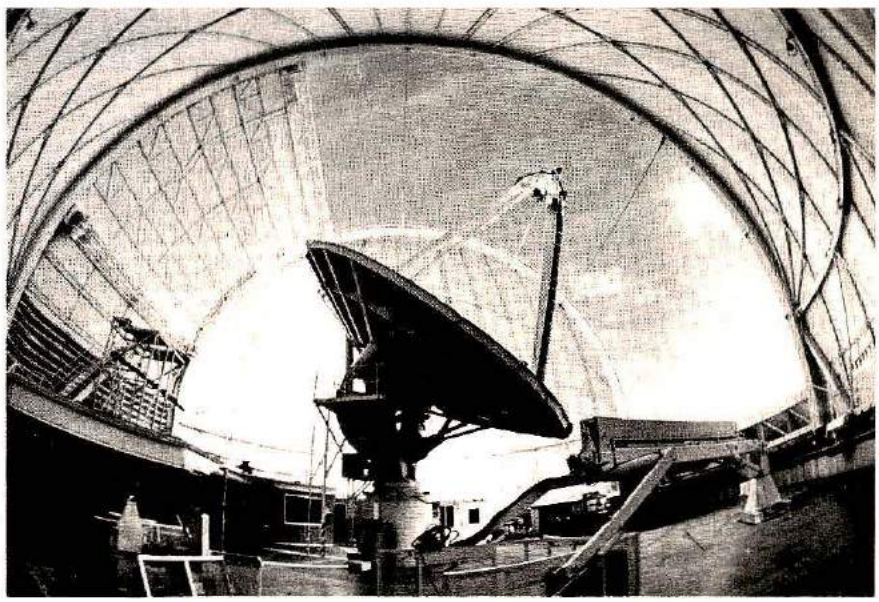
the two moveable elements: about 5000 feet (1500 meters). Though less sensitive than a real telescope of that size, the addition of longer hours of observation for higher resolution makes it well worthwhile.

The most imposing instrument is the 140-foot (43 meter) scope, completed in May, 1965, at a cost of almost $14,000,000. It was this telescope that was used to discover formaldehyde, the first organic molecule found in space.

The largest of NRAO's telescopes, and the one used to find the Crab Nebula pulsar, is a 300-foot (92 meter) dish with a surface area of 1.8 acres (7300 square meters). After its completion in 1962, for almost a decade it was the largest moveable radio telescope in the world.

One telescope not located in West Virginia is a special, high-frequency dish at Kitt Peak National Observatory (KPNO), near Tucson, Arizona. KPNO is the optical counterpart to NRAO and was chosen as a site for a radio telescope for the same reasons that the visual astronomers first claimed the peak: clarity of atmosphere at high altitude, an important consideration for super-high-frequency work. Hence, the choice of a single 36 foot (11 meter), millimeter wavelength telescope for Kitt Peak, the heart of "enemy" territory. (At one time there was a small, 6-inch [15cm], optical

When the wavelengths get so short that they are in what is termed the millimeter-wave band, the surface of the dish must be very accurate to be efficient. This mm-wave telescope is housed in a radome at Kitt Peak, near Tucson, Arizona. The 36-foot (11m) instrument is operated by NRAO in a study of the cold gas in the Milky Way (*photo courtesy NRAO*).



telescope at Green Bank, but, hinting of a radio *vs* visual rivalry that still survives in astronomy, it is referred to as a "toy" and never used.)

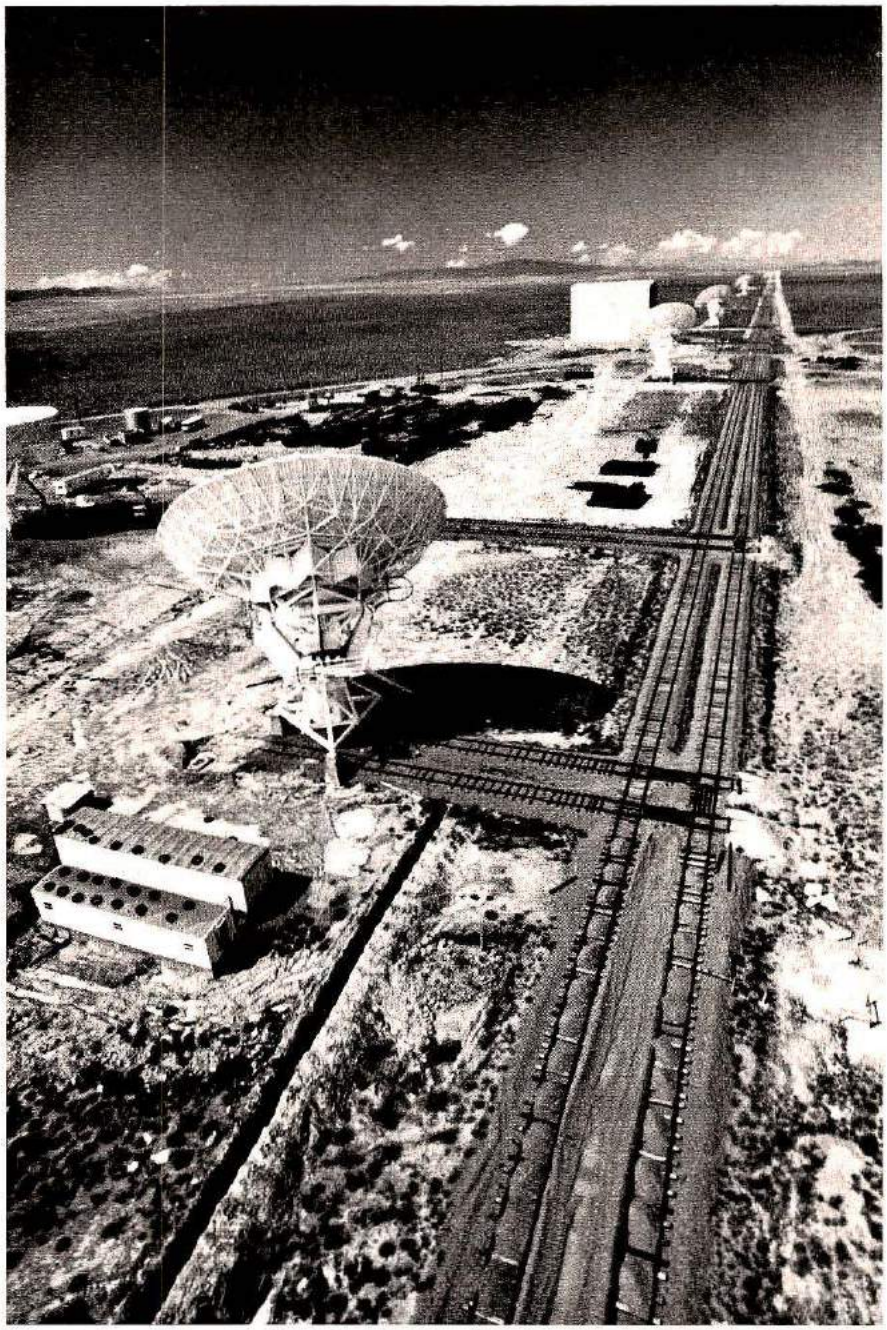
Green Bank, however, remains an ideal site for reception at lower frequencies. To the residents' chagrin, it is virtually impossible for them or the telescopes to pick up commercial radio and television. And, since a state zoning law forbids flying over the NRAO sites, the equipment is safe from aeronautical interference.

Also, the mountains soften the elements. There is little snowfall and the humidity is relatively low year round. Though the telescopes are operational in winds up to forty miles per hour, velocities seldom approach gale force. If they do, the dishes are swung to a "stow," or vertical position, in which the sloped underside of the bowl acts as an airfoil and actually forces the wind to help support it.

Despite their ruggedness, each of the telescopes require eight hours of shut-down time, every week, for maintenance. Only the personal intervention of the director himself can override this procedure.

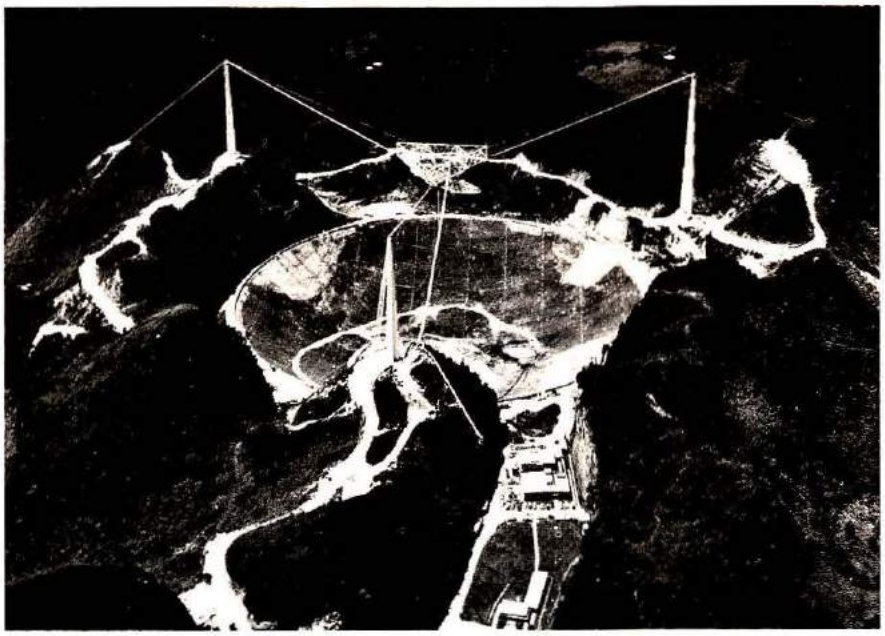
Larger projects and equipment

That kind of care will be even more necessary in the future. The reason is that 1973 witnessed the first NSF (National Science Foundation) money — $3,000,000 — toward a project referred to in Charlottesville as the VLA, or Very Large Array. The name is accurate. When completed in 1981, the VLA will be a complex of 27 telescopes, each 25 meters across, spread over a circular area many miles in diameter. Working together, the telescopes will form a giant interferometer, with nine dishes on each of three tracks splaying out from a central hub like the spokes of a peace symbol. The VLA will easily recapture the title of "world's largest" for NRAO. At a total price of $80,000,000, it will also be the "most expensive."



At the Very Large Array site in New Mexico, one leg of the system stretches to the northeast horizon. A unique set of bogey wheels on the transporter allows the dishes to be brought to the main track from the spur, then moved at right angles, to another position. The large building between the second and third antennas is an assembly and repair facility. It is large enough that a complete 82-foot (25m) antenna can be worked on inside. The facility is built in a Y configuration, with two arms 13 miles (21km) in length, and another that is 11.8 miles (19km) long. When it is finished, the 27-dish installation will have the resolving power of a single dish approximately 26 miles (42km) in diameter (*photo courtesy NRAO*).

The VLA, however, is not being constructed at Green Bank. The new site is over 1500 (2400 km) miles west and may cause some rather non-scientific administrative problems. The new location, on the Plains of St. Augustin, in the Magdalena Mountains, outside of Socorro, New Mexico, will eventually employ over 60 people. Because of its



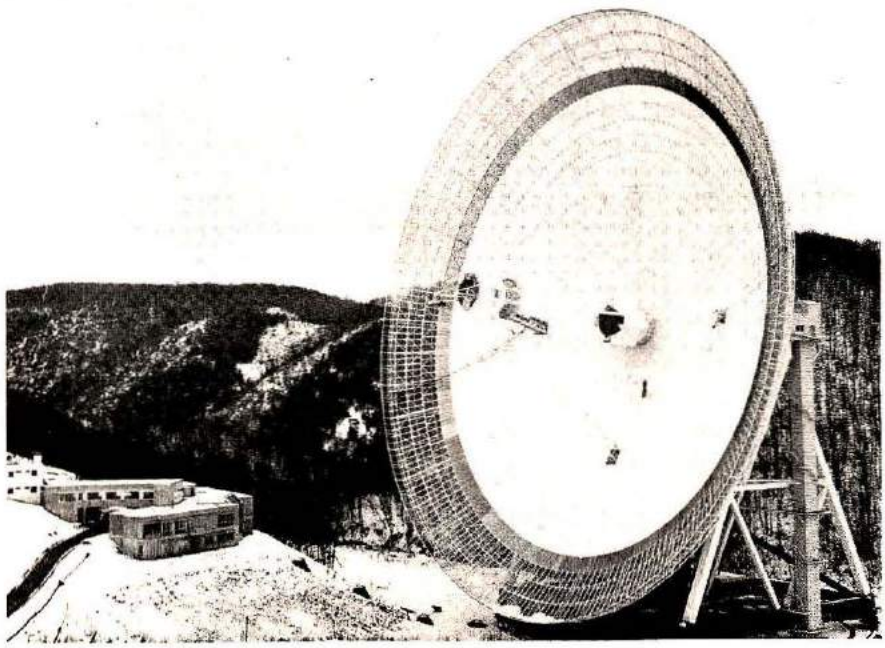
For truly awesome contemplation there is the 1000-foot (305m) installation at Arecibo, Puerto Rico. A depression in the terrain was expanded and shaped, then lined with cables and surfacing panels. Since this photograph was taken the surface has been fitted with panels of greater accuracy to extend the upper frequency range of the dish. It has seen such diverse uses as radar sources, and for Amateur Radio communication by bouncing signals off the moon.

size and the personnel involved, the Socorro site will not be as easily run by remote administrative controls as is the much smaller Kitt Peak operation.

Both the Green Bank and Charlottesville locations will remain in full operaton; the seat of power, at any rate, will remain in Virginia. But, since some of the scientific equipment will have to be constructed in New Mexico, there may be a transfer or duplication of some personnel. Beyond that, some non-scientists, in purchasing and accounting, may also be involved in the move.

The important thing to remember about NRAO's administrative pains is that they are the growing kind and not unpleasant. They mean expansion on a grand scale. In the last few years, NRAO's budget has doubled; by 1981, facilities will double. All of which means that radio astronomy will move closer to equality with its older brother, optical astronomy. It will help give the entire science a sort of binocular vision, a way to see the universe in true perspective and depth.

Other parts of the world are into the Radio Astronomy studies too. The Max Planck Institute for Radio Astronomy in Germany has this 330-foot (100m) dish that is steerable in both azimuth and elevation. In addition to looking for emissions from 50-billion light years away, it will be used to receive signals from a Helios space probe being built jointly by the United States and Germany.



Recommended Reading

1. John Heywood, *Radio Astronomy and How to Build Your Own Telescope*, Arc Books, Inc., New York,1964.

2. *Scientific American*, Vol. 206, No. 2, "The Amateur Scientist," February, 1962, pages 163-174.

3. Dennis M. Downes, "A Simple Radio Telescope," *Sky and Telescope*, Vol. 24, No. 2, August, 1962, pages 75-76.

4. Joseph H. Alexander and Larry W. Brown, "A Radio Telescope For Amateurs," *Sky and Telescope*, April, 1965, Vol. 29, No. 4, pages 212-214.

5. J. Kraus, *Big Ear*, Cygnus-Quasar Books, Powell, Ohio, available from *ham radio's* Communications Bookstore, No. CQB-A, $3.25.

6. F.S. Harris, "The Parametric Amplifier," *CQ Magazine*, November, 1958, pages 74-75; 159, 164, and 168.

7. Heiserman, *Radio Astronomy for the Amateur*, Tab Books, Blue Ridge Summit, Pennsylvania, available from *ham radio's* Communications Bookstore, No. T-714, $5.95.

8. J. Shields, *Introduction to Radio Astronomy*, Howard W. Sams, Blue Summit, Pennsylvania, available from *ham radio's* Communications Bookstore, No. 21246, $4.50.

HRH